BNL NP Lattice Gauge Theory

Frithjof Karsch

BROOKHAVEN NATIONAL LABORATORY

What has been put on the agenda:

– Recent highlights and plans in Lattice QCD
– BNL hardware usage and plans
– Synergies with RBRC and HEP theory efforts

Members of the LGT Group

Frithjof Karsch (senior scientist, tenure)
Peter Petreczky (scientist, tenure since 12/2010)
Swagato Mukherjee (assistant scientist, since 9/2009; scientist, starting 10/2014)

FK is member of the USQCD Executive Committee;
P. Petreczky is member of the Scientific Program Committee

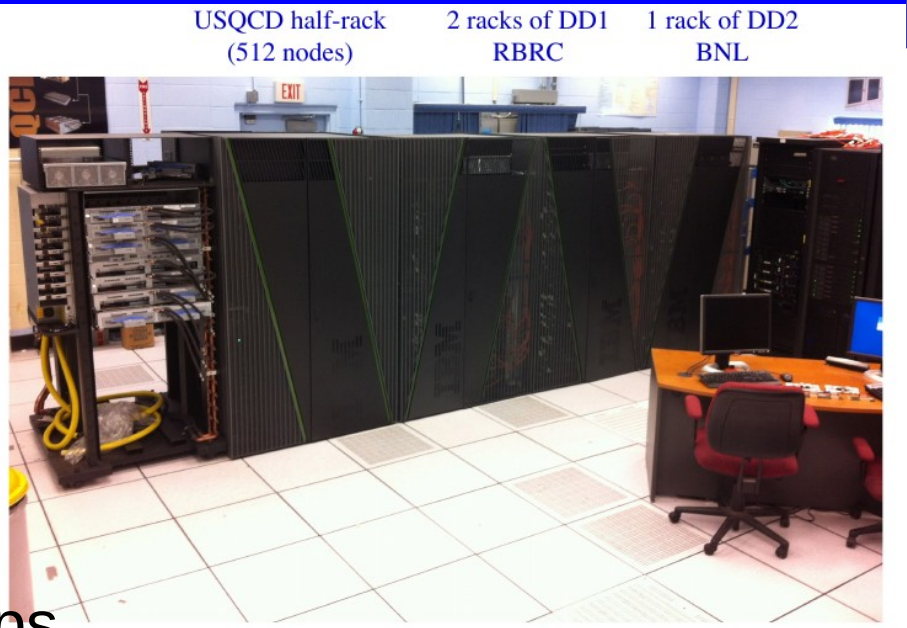
post-doc: Sayantan Sharma (starting 10/2014)

former post-docs: Alexei Bazavov (until 9/13 no replacement)
Heng-Tong Ding (until 10/13 no replacement)
Yu Maezawa (until 10/13)

other group members:
Chulwoo Jung (joint NP/HEP SciDAC-3 appointment)
Hiroshi Ohno (2-year leave from Tsukuba University, since 6/2014)

pending LDRD-proposal (jointly with CSC&HEP):
support software development for future Xeon Phi based exascale hardware

BNL hardware



current hardware at BNL:

RIKEN/BNL:
2 prototype racks of
BlueGene/Q (DD1); 400 TFlops

BNL:
1 prototype rack of BGQ (DD2); 200 TFlops
BlueGene/P: 2 racks operated by BNL for the NYCCS

USQCD: ½ rack BlueGene/Q operated at BNL for USQCD

LGT group uses~1/8 of RIKEN/BNL BGQ; ~1/4 of BNL BGQ

Software development: FK coordinates US-wide NP SciDAC-3 grant
and is PI of the BNL part of a HEP SciDAC-3 grant;
approved NESAP project (NP-Columbia/HEP)

non-BNL hardware resources

main compute resources for LGT group

I) access to USQCD hardware at JLab and FNAL:

- clusters at FNAL and JLab
- GPU-cluster at JLab

II) hotQCD receives 20% of USQCD's INCITE grant on BGQ at Argonne and 40% of the INCITE grant on Titan at ORNL + zero priority time

III) access to BGQ at LLNL

IV) access to the 400 GPU cluster at Bielefeld University, Germany

III and IV are made possible through the hotQCD Collaboration (III) and the Bielefeld-BNL-Wuhan Collaboration (IV)

Publications and Citations

source: SPIRES, September 2014 (refereed journals only)

tenured staff member	career publications no. of publ.	citations	publications 2011—8/2014 no .of publ.	citations
Frithjof Karsch	209	17016	20	840
Peter Petreczky	84	6947	18	803

recent top cited paper of NP Lattice Gauge Theory group

– A. Bazavov et al (hotQCD Collaboration), The chiral and deconfinement aspects of the QCD transition , Phys. Rev. D85, 054503 (2012) [#1 topcite 2013] [295 citations]

$$T_c = (154 \pm 9)\ \mathrm{MeV}$$

- total number of publications during 2011-8/2014 in refereed journals: 26
  no. of citations: 977

  4 Physical Review Letters

Recent Research Highlights

- Freeze-out conditions in Heavy Ion collisions from conserved charge fluctuations

BI-BNL-CCNU

  – comparing exp data with lattice QCD calculations

A. Bazavov et al., Phys. Rev. Lett. 109 (2012) 192302

- dissolution of open strange hadrons in the QGP and their influence on freeze-out conditions in heavy ion collisions

  – strange hadrons melt at Tc

BI-BNL-CCNU

A. Bazavov et al., Phys. Rev. Lett. 111 (2013) 082301

  – yet unobserved hadrons influence the determination of T-freeze

A. Bazavov et al., Phys. Rev. Lett. 113 (2014) 072001

A. Bazavov et al., Phys. Lett. B737 (2014) 210

highlighted as PRL editors suggestion

- determination of the chiral transition temperature using chiral fermions

  – first determination of Tc with domain wall fermions

  – analysis of UA(1) breaking in the vicinity of Tc

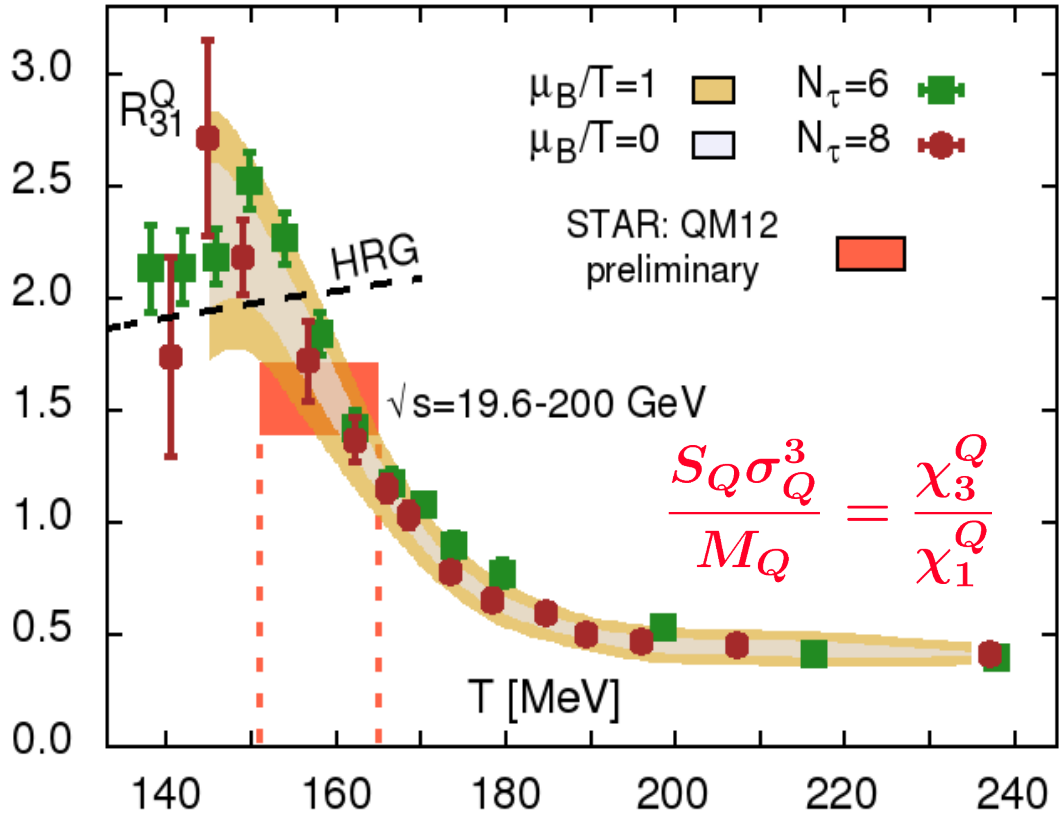
hotQCD

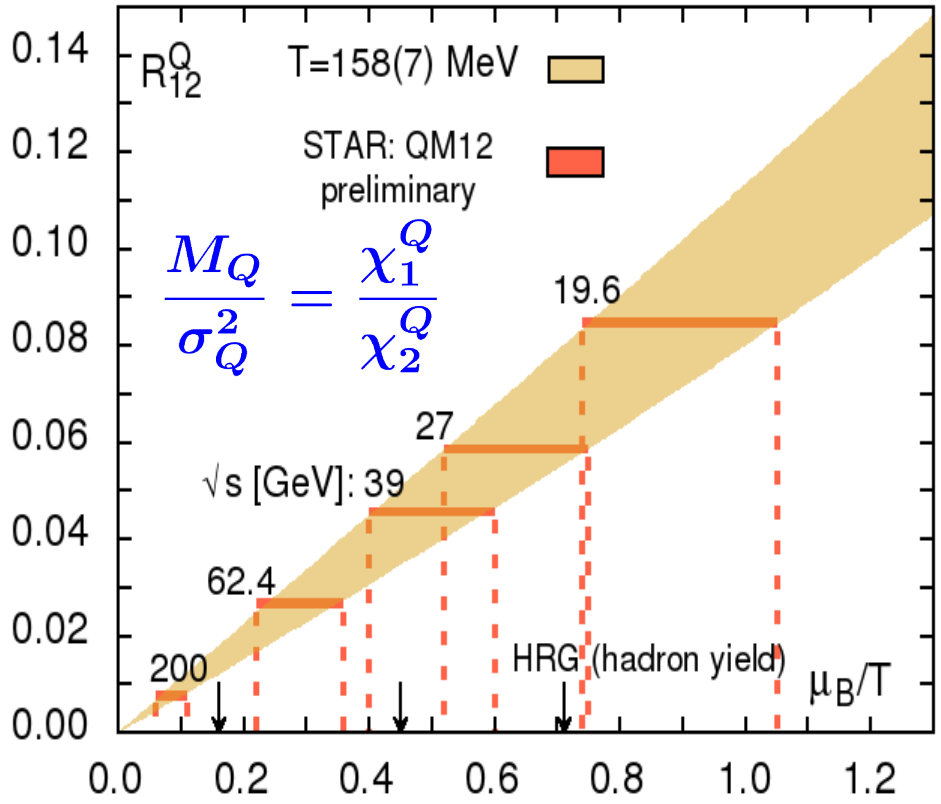
T. Bhattacharya al., Phys. Rev. Lett. 113 (2014) 082001

highlighted as PRL editors suggestion

Freeze-out in HIC from LQCD

net electric charge fluctuations





"thermometer": determines freeze-out temperature

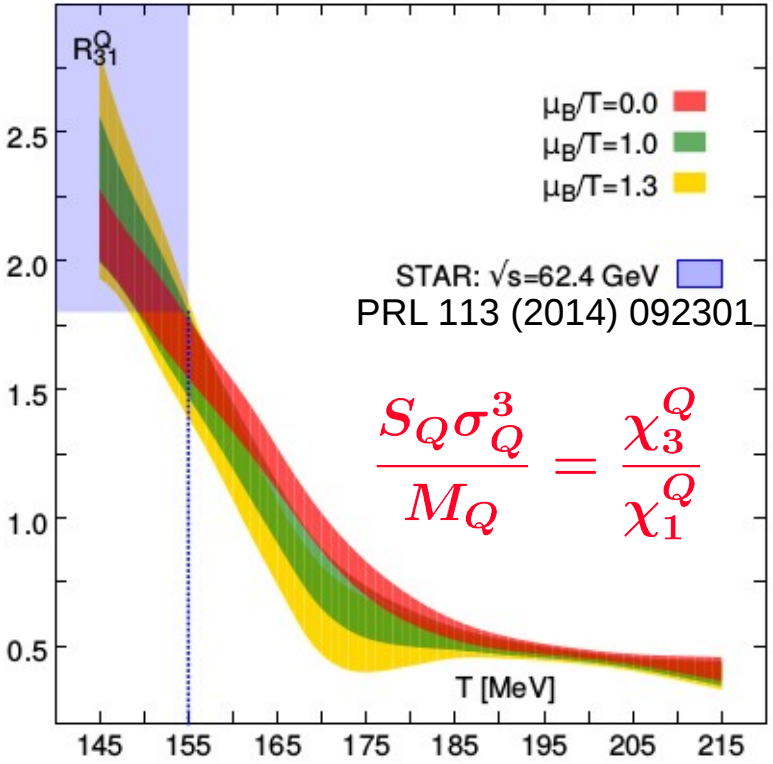
"baryometer": determines freeze-out chemical potential

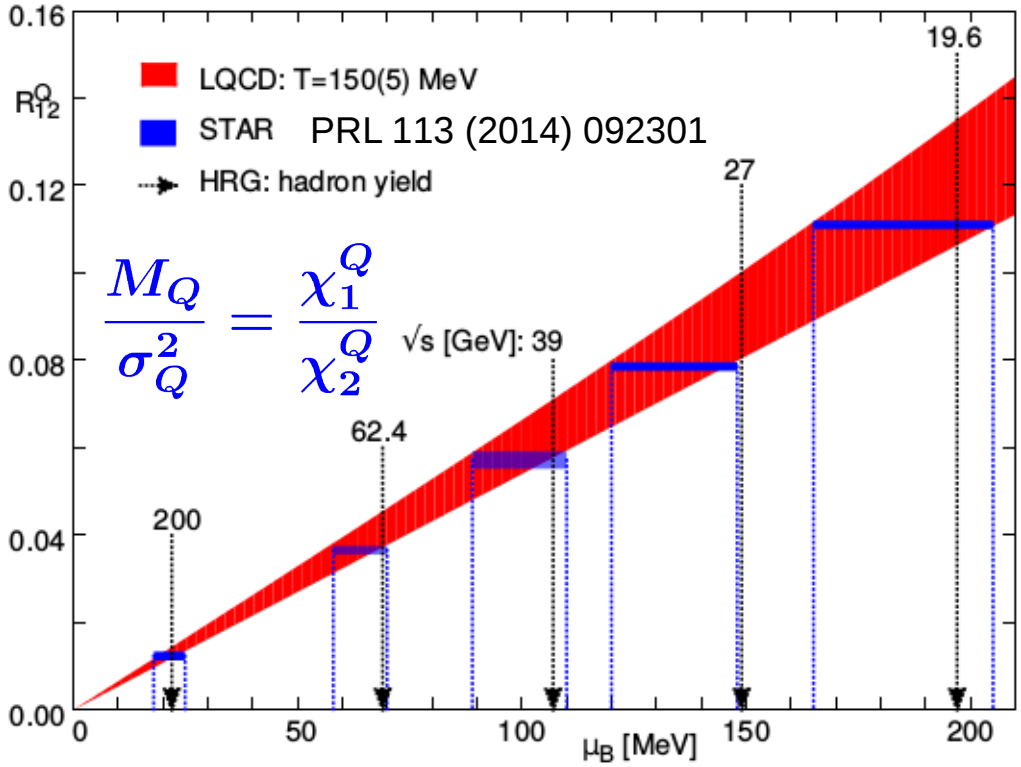
BNL-Bielefeld: Phys. Rev. Lett. 109, 192302 (2012)

Freeze-out in HIC from LQCD

net electric charge fluctuations

Swagato Mukherjee, LRP Town Hall Meeting





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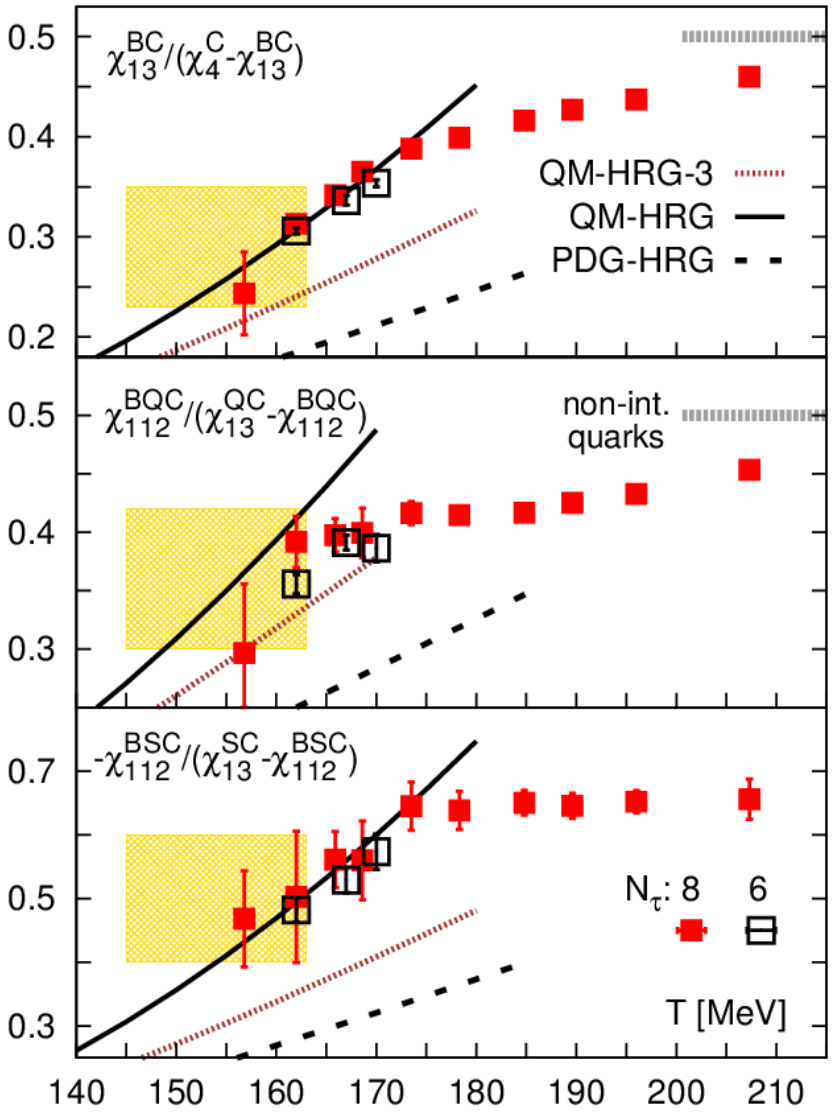
BNL-Bielefeld: Phys. Rev. Lett. 109, 192302 (2012)

Evidence for many charmed baryons in thermodynamics



close to Tc charmed baryon fluctuations are about 50% larger than expected in a HRG based on known charmed baryon resonances (PDG-HRG)

charmed pressure ratios

all charmed baryons/mesons

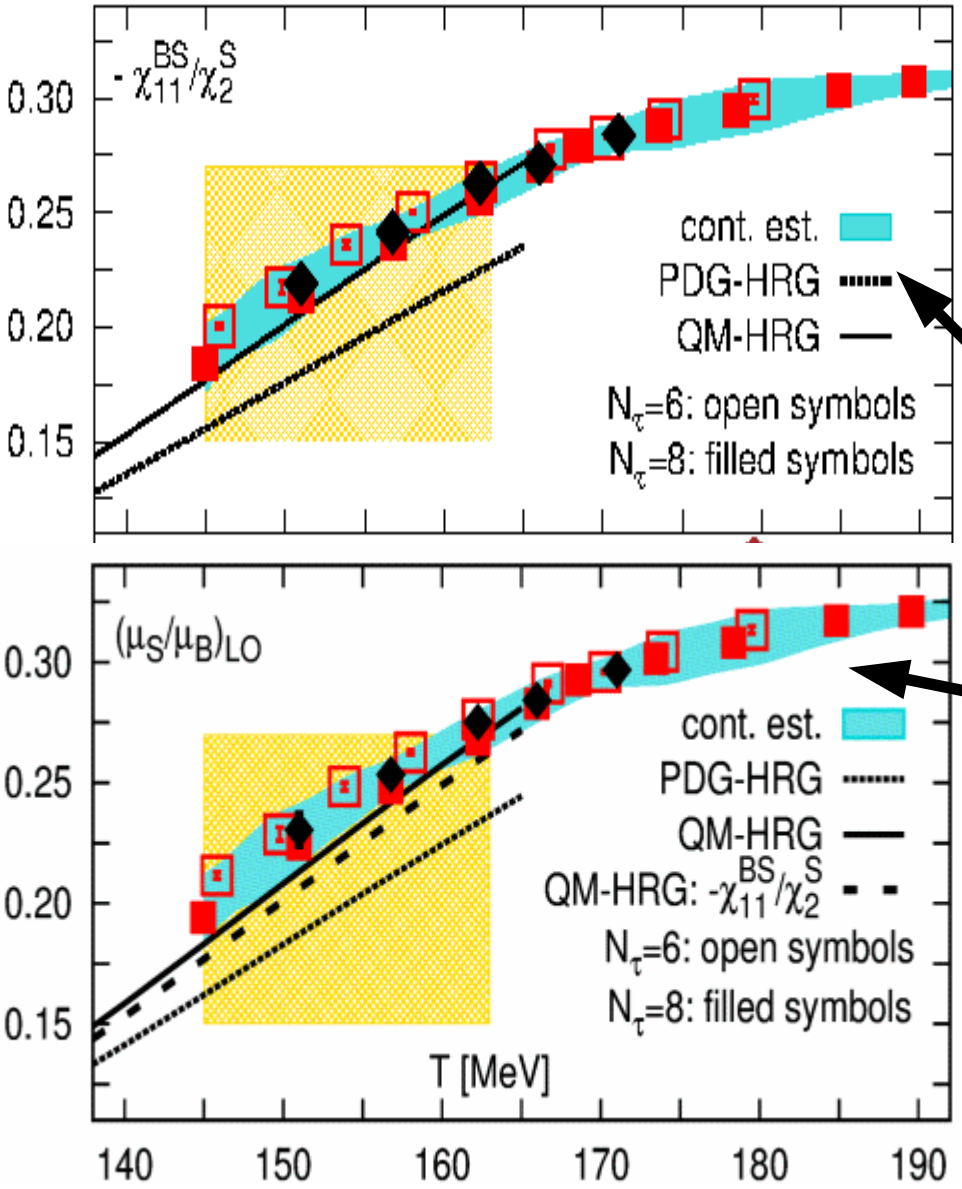
charged charmed baryons/mesons

strange charmed baryons/mesons

including resonance predicted in quark model calculations and observed in lattice QCD calculations allows for a HRG model (QM-HRG) description of lattice QCD results on conserved charge fluctuations and correlations

A. Bazavov et al., Phys. Lett. B737, 210 (2014)
arXiv:1404.4043

Evidence for more strange baryons in thermodynamics



close to Tc strange baryon fluctuations are about (10-20)% larger than expected in a HRG based on known strange baryon resonances (PDG-HRG)

QM-HRG model agrees well with lattice QCD

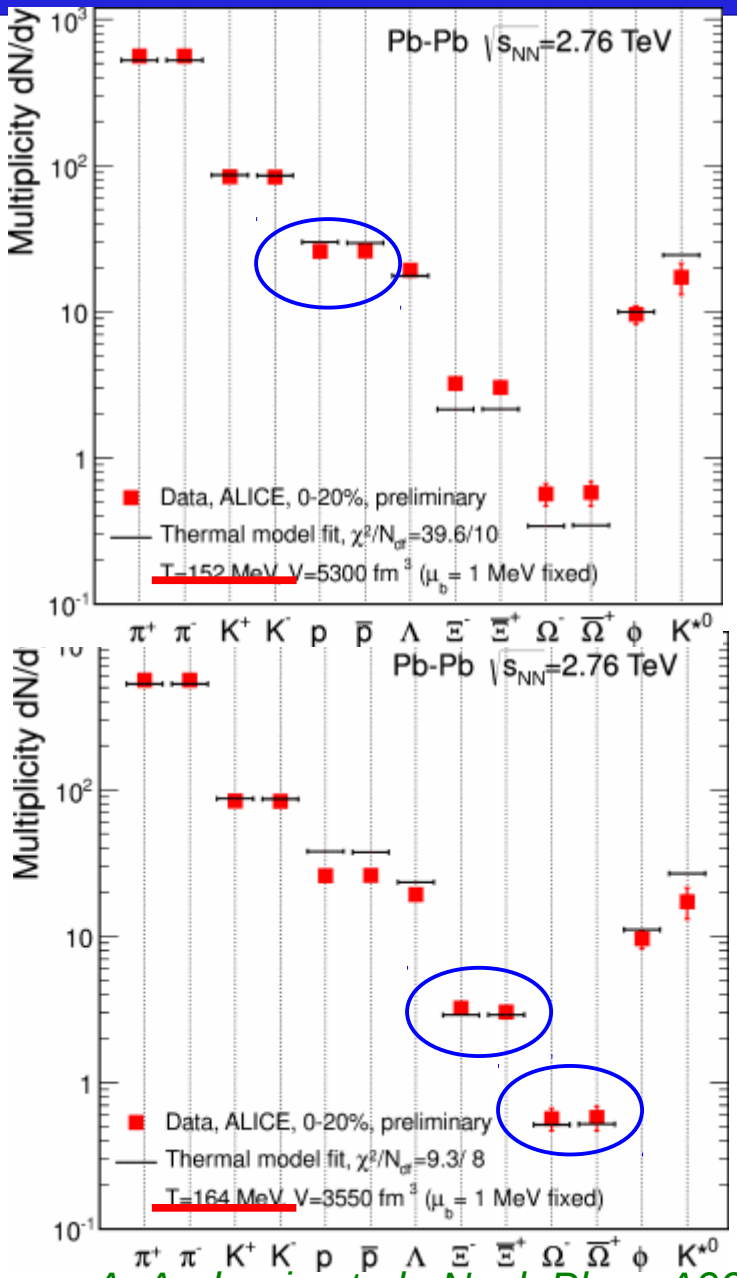
enhanced
strangeness-baryon correlation over strangeness fluctuations

strangeness neutrality
enforces relation between chemical potentials

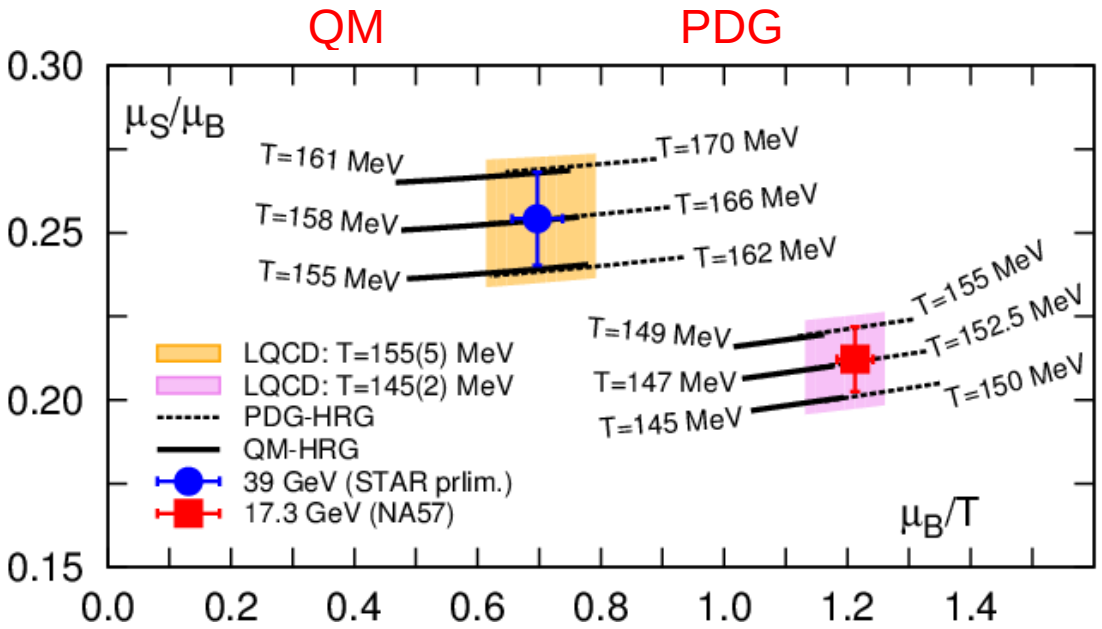
$$\langle n_S \rangle = 0$$
$$= \chi_2^S \hat{\mu}_S^2 + \chi_{11}^{BS} \hat{\mu}_S \hat{\mu}_B + \mathcal{O}(\mu^4)$$
$$\frac{\mu_S}{\mu_B} = -\frac{\chi_{11}^{BS}}{\chi_2^S} + \mathcal{O}(\mu^2)$$

A. Bazavov et al. (BI-BNL-CCNU Collaboration), Phys. Rev. Lett. 113, 072001 (2014), Phys. Rev. Lett. 111, 082301 (2013)

Impact on determination of freeze-out parameter

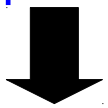


A. Andronic et.al.: Nucl. Phys. A904, 535c (2013)



A. Bazavov et al., Phys. Rev. Lett. 113, 072001 (2014), arXiv:1404.6511

including more strange baryons will change determination of freeze-out parameters



better agreement of strange and non-strange particle yields at lower freeze-out temperature

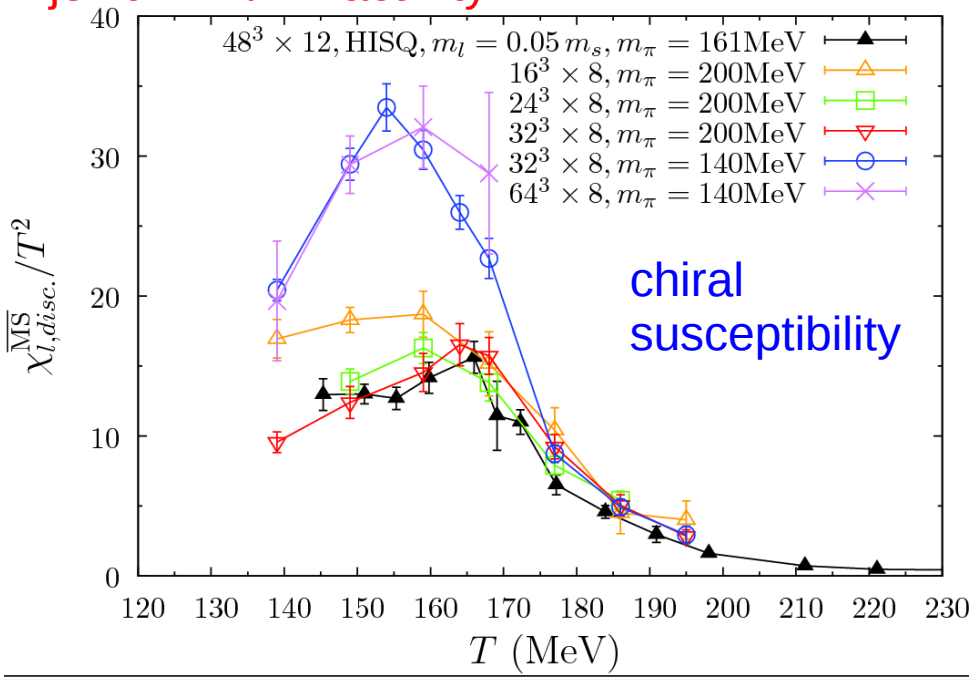
Thermodynamics with chiral fermions

- using a chiral fermion formulation (DWF) for thermodynamic calculations allows to perform a more rigorous analysis of the role of the axial $U_A(1)$ symmetry close to T_c ;

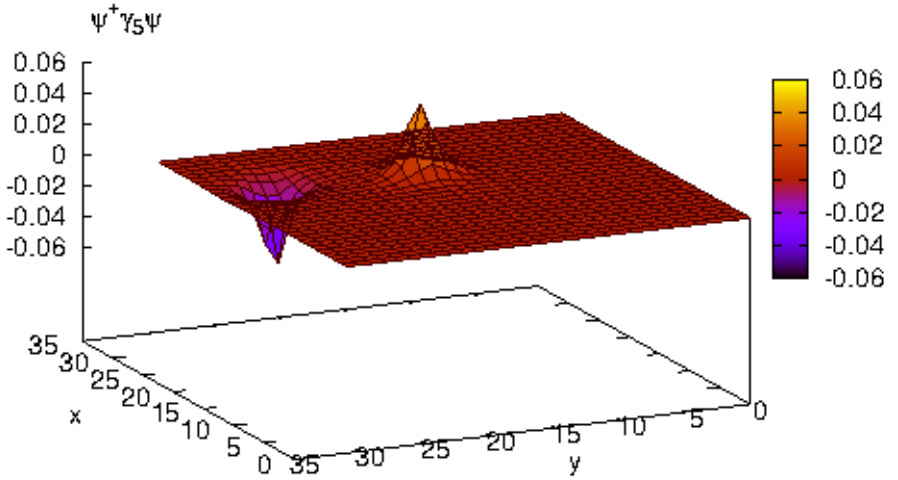
ongoing project of hotQCD on BGQ ;

T. Bhattacharya al., Phys. Rev. Lett. 113 (2014) 082001
M. Buchoff, Phys. Rev. D89 (2014) 054514

program development: Chulwoo Jung;
joint HEP/NP activity



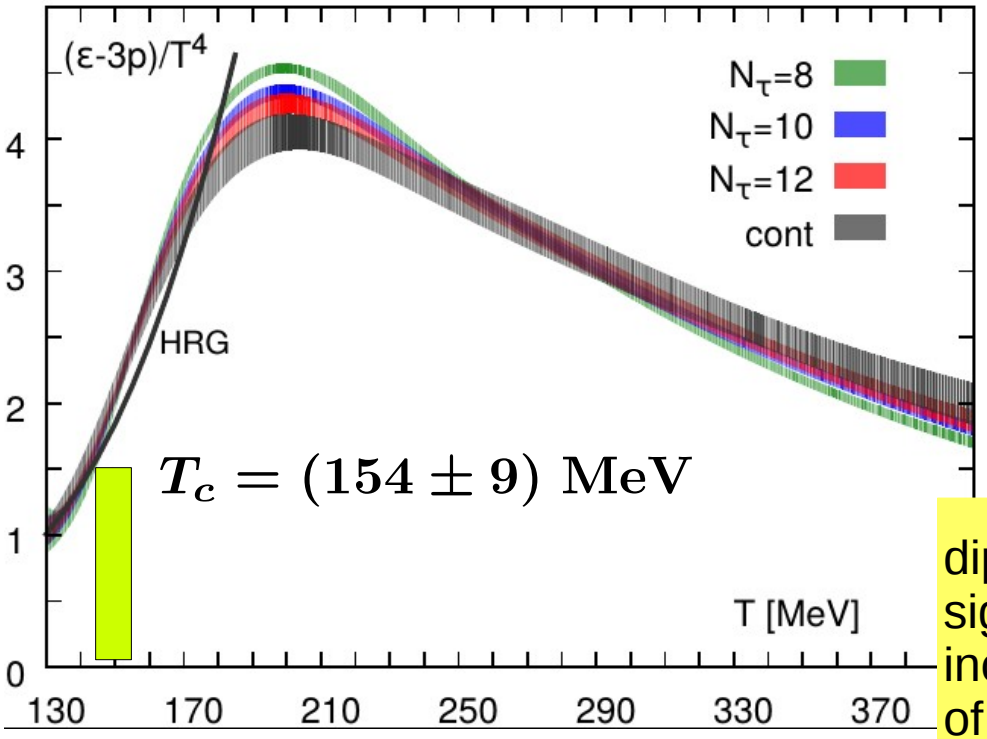
flavor symmetry restoration;
UA(1) remains broken at Tc;
gross features of an "instanton gas" verified

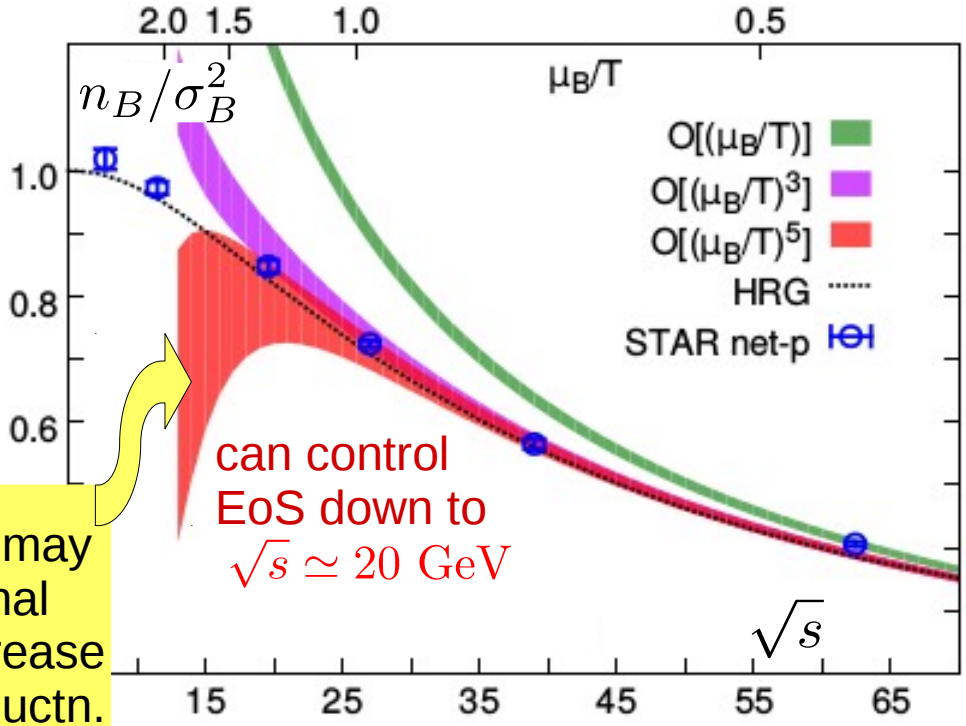


QCD Equation of State

- hotQCD has published the continuum extrapolated EoS for (2+1)-flavor QCD hotQCD , arXiv:1407.6387
  - good agreement with Wuppertal-Budapest results
- BI-BNL-CCNU collaboration performs first calculation of the EoS at non-zero chemical potential up to O(mu^6)

P. Hegde, arXiv:1408.6305 (Quark Matter 2014)
S. Mukherjee, LRP Town Hall Meeting





dip may signal increase of fluctn.

can control EoS down to $\sqrt{s} \simeq 20$ GeV

Future Plans – Ongoing Project

– conserved charge fluctuations and the low energy run at RHIC

3-year USQCD INCITE hotQCD project on Titan at ORNL and BGQs at ALCF and LLNL

– highly efficient GPU code developed by BI-BNL collaboration

– extend calculations of charge fluctuations to sixth order

develop programs for better noise reduction as part of the SciDAC-3 project

– joint NP/HEP effort

– prepare for the next generation of leadership class computers based on Xeon-Phi processors

I) approved NERSC exascale application project (joint NP/HEP BNL-Columbia project) starts in FY15

II) pending LDRD project (joint NP-HEP-CSC proposal)

Conclusions

– the NP LGT group/hotQCD has completed the calculation of the QCD transition temperature and equation of state at vanishing baryon chemical potential

– the currently performed sixth order Taylor expansion of the EoS in baryon chemical potential will provide the EoS needed in the RHIC beam energy scan down to beam energies of 20GeV

– the group has constructed a set of fluctuation observables that can directly be compared to data on charge fluctuations obtained in the beam energy scan

– in order top be able to perform these state-of-the art calculations, the development of efficient software for GPU enhanced computers was essential

– adequate post-doc support is needed to sustain this high level of research also on the next generation of leadership class computers